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Landfill Carbon Storage and Greenhouse Gas Inventories

White Paper

Prepared for

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Background and Objective

Although landfills are a well-known source of methane and other greenhouse gas emissions, they also store significant amounts of carbon. This storage, or "sequestration," is important because it removes carbon from the natural carbon cycle indefinitely, reducing net emissions of greenhouse gases.

Greenhouse Gas Inventories

A greenhouse gas inventory takes stock of the amount of greenhouse gases emitted to or removed from the atmosphere by human activities over a period of time, usually a year. Inventories also describe human-related sources and sinks of greenhouse gases. Greenhouse gas inventories may be prepared for nations, regions, states, companies, or even individual households.

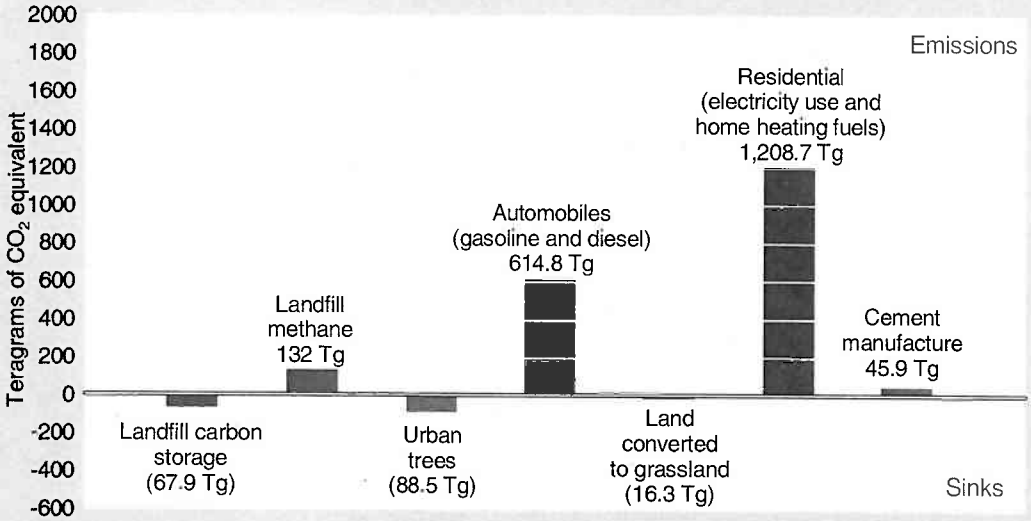
Greenhouse gas inventories are used by policy makers to monitor trends, develop strategies to reduce emissions and enhance sinks, and assess progress toward their goals. Inventories are also used by scientists to monitor trends and as a source of data for model projections.

The effect of this process on overall U.S. greenhouse gas emissions is quite significant. In comparison to other sources and sinks in the U.S. GHG inventory, the annual increase in storage of carbon in landfills in 2005

- Offset 51 percent of landfill methane emissions
- Exceeded, in absolute magnitude, the emissions from 47 of the 54 source categories (U.S. EPA, 2007).

For perspective, Exhibit 1 shows the relative magnitude of carbon storage in landfills compared to several other well-known categories of greenhouse gas sources and sinks, based on the 2005 U.S. GHG inventory (U.S. EPA, 2007).

Exhibit 1.
Comparison of annual emissions and storage of carbon in landfills with selected other sources and sinks, 2005



Source: EPA, 2007. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2005.

The international guidelines for conducting greenhouse gas inventories, developed by the Intergovernmental Panel on Climate Change (IPCC), provide the basic framework and methodologies for developing national inventories of human-generated greenhouse gas emissions and removals. The U.S. Environmental Protection Agency (EPA) follows IPCC's protocols in developing its annual Inventory of

U.S. Greenhouse Gas Emissions and Sinks (U.S. Inventory). Both IPCC and EPA recognize and account for carbon sequestration of undecomposed wood products; EPA additionally accounts for carbon sequestration of food scraps and yard trimmings (branches, leaves, grass) disposed of in landfills.

Despite this recognition at the international and national levels, carbon sequestration in landfills is often overlooked or misunderstood in state greenhouse gas accounting efforts.

This white paper provides a non-technical overview of:

1. The carbon storage process in landfills,
2. The rationale for reporting landfill carbon storage in inventories,
3. IPCC's guidance on accounting for landfill carbon storage in inventories,
4. How carbon storage has been addressed in the Inventory of U.S. Greenhouse Gas Emissions and Sinks, and
5. The rationale for providing a complete characterization of greenhouse gas emissions and sinks for landfills within greenhouse gas inventories.

The remainder of the paper addresses these elements, and cites references for those seeking a more detailed, technical discussion of specific issues.

1. Carbon Storage Processes in Landfills

Carbon is naturally removed from the atmosphere and stored in forests (and then in harvested wood products, e.g., paper, lumber, furniture), yard trimmings, and food scraps via photosynthesis. Once these materials are disposed of in a landfill, only a portion of them will decompose, while a portion will remain stored in the landfill indefinitely. Decomposition of the waste creates landfill gas, which is primarily composed of methane (CH_4) and carbon dioxide (CO_2), as well as small amounts of volatile organic compounds (VOCs). Some carbon may also be dissolved in leachate, which is collected and treated or re-circulated within the landfill.

The proportion of the solid waste in landfills that decomposes depends on the type of waste, the amount of moisture, and other factors that affect the growth of microbes that break down the waste , and whether the landfill is operated to retard or enhance waste decomposition (Freed et al. 2004).

. Freed et al. (2004) explain this process in detail:

> "On a dry weight basis, municipal refuse contains 30-50% cellulose, 7-12% hemicellulose, and 15-28% lignin (Hilger and Barlaz 2001). While the degradation of cellulose and hemicellulose in landfills is well documented, lignin[1] does not degrade to a significant extent under anaerobic conditions (Colberg 1988). In fact, while cellulose and hemicellulose biodegradation does occur, the extent of decomposition varies with landfill conditions and these materials do not appear to completely degrade based on a number of excavation studies (Ham and Bookter 1982, Wang, et al. 1994, Ham, et al. 1993). In addition, the presence of lignin actually prevents some cellulose and hemicellulose biodegradation. Thus, landfills in effect store some of the cellulose and hemicellulose and all of the lignin that is buried initially. The amount of storage will vary with environmental conditions in the landfill, with pH and moisture content identified as the two most important variables controlling decomposition (Barlaz, et al. 1990)."

Landfill carbon storage can be calculated as the total carbon entering the landfill minus the carbon leaving as methane, carbon dioxide, volatile organic compounds, or dissolved in leachate (see Exhibit 2).

[1] Cellulose, hemicellulose, and lignin are all found in the cell wall of plants, and they are the predominant carbon-containing materials in paper and wood waste.

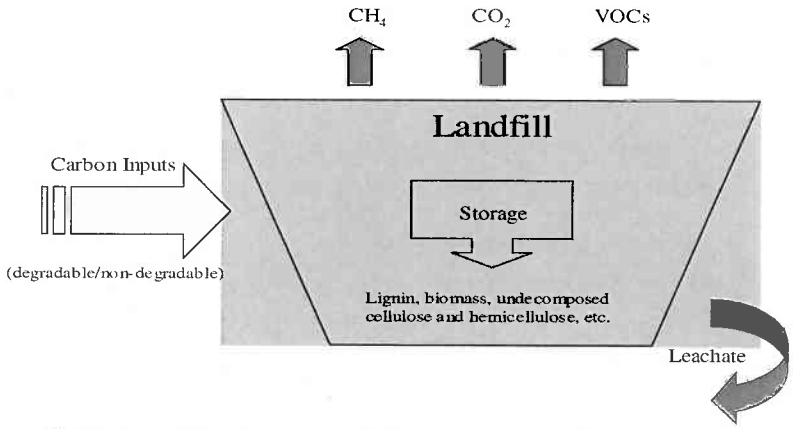


Exhibit 2. Landfill carbon mass balance approach (Freed et al. 2004)

Although waste management activities are associated with a variety of different greenhouse gas emission and sink categories (U.S. EPA 2006), landfill methane emissions are the largest single source within this sector, comprising 2.1% of net U.S. emissions (U.S. EPA 2007). Despite an increase in waste disposed in landfills, methane emissions have decreased by approximately 18 percent from 1990 through 2005 as a result of increased use of sophisticated landfill gas collection and combustion devices. Although the focus of most analysts has been on landfill methane, landfill carbon storage is also an important process.

2. Rationale for Reporting Landfill Carbon Storage in Inventories

Greenhouse gas inventories account only for changes in greenhouse gas emissions or removals that are anthropogenic (i.e. caused by human activities). The Earth has a natural carbon cycle in which carbon flows among four large reservoirs: the atmosphere, the biosphere (living things, whose emissions or removals are referred to as "biogenic"), the hydrosphere (oceans and freshwater), and the geosphere (solid Earth). In the absence of human activities, the amount of carbon dioxide going into the atmosphere is balanced by the amount of carbon dioxide removed by plants and the oceans. Human activites such as burning fossil fuels (which introduce carbon into the system that had been locked away in the geosphere for millions of years) and deforestation (which reduces the amount of CO_2 removed from the atmosphere by trees) upset this natural balance.

In landfills, CO_2 emissions from aerobic decomposition are not counted in inventories because that decomposition is part of the natural carbon cycle. On the other hand, methane emissions that result from anaerobic decomposition in a landfill *are* counted in inventories, because anaerobic decomposition would most likely not have occurred if the materials had not been disposed in the artificial environment of a landfill.

By the same logic, when harvested wood products and other organic materials such as yard trimmings and food scraps are disposed of in landfills, the portion that is no longer available to the atmosphere should be accounted for in inventories as a sink, because it represents carbon removed from the system by human activities. If these materials had been left to decompose naturally, they would have returned their carbon to the naturally occurring biogeochemical cycle.

3. IPCC's Inventory Guidance on Accounting for Carbon Storage

IPCC recognizes and accounts for carbon storage in landfills, as a means of providing a complete and systematic accounting of the carbon cycle that originates in managed forests and ends in ultimate disposal of harvested wood products. Thus, IPCC's guidance on addressing carbon accumulation in landfills is provided under the category of accounting for carbon in Harvested Wood Products (HWP). IPCC does not provide guidance on landfill carbon storage from yard trimming and food scrap sources, although the U.S. EPA does account for carbon storage from these materials in its U.S. Inventory.

Estimating Carbon in Harvested Wood Products

HWP includes all wood material that leaves harvest sites on forested land. The wood-derived carbon is stored in various products used by consumers—such as newspaper and structural timber—for differing lengths of time. Once a product is no longer in use, it can be disposed of in different ways, which have different implications for how the carbon in the product remains stored or is released. For example, if the product is destined for waste combustion, essentially all of the carbon is converted to carbon dioxide. If the product is disposed in a landfill, it is subject to the more complex fate described above, with the dominant fates being long-term storage and anaerobic decomposition (which emits approximately equal amounts of methane and carbon dioxide).

IPCC offers several approaches for estimating changes in the amount of carbon stored in wood products within a country, but all of them recognize and account for accumulation of HWP carbon in landfills.

Completeness and Transparency

IPCC's guidelines suggest that inventories should be "consistent, comparable, complete, accurate and transparent" (IPCC 2006). In general, for calculations using a mass balance approach (a complete accounting of material entering and leaving a system, based on the law that matter cannot be created or destroyed), it follows that inventories should report all elements of the mass balance in order to be transparent. Since inventory compilers already have to calculate the accumulation of carbon in landfills, we believe that in principle they should report it in the inventory.

With specific regard to HWP, the IPCC guidelines state that it is good practice to document "all information used to produce national estimates of stock change. … [Additionally, the] inventory report should contain summaries of methods used and references to source data so that the steps used in making the estimates can be retraced" (IPCC 2006).[2] In order to follow this good practice guideline, both the change in carbon storage in landfills and the emissions from landfills should be reported.

4. Carbon Storage in the U.S. Greenhouse Gas Inventory

Carbon storage in landfills is accounted for in the U.S. Greenhouse Gas Inventory, in the context of both (a) changes in the amount of carbon stored in forests (specifically in terms of carbon being harvested and subsequently stored in HWP) and (b) changes in the amount of yard trimming and food scrap materials disposed in landfills. The methods used in the U.S. Inventory have been subject to annual peer, expert, and public reviews, as well as numerous international reviews conducted by inventory experts under the auspices of the U.N. Framework Convention on Climate Change. Thus, the methods and results have been subject to—and withstood—intense and repeated scrutiny. In fact, the IPCC 2006 guidelines for HWP are derived largely from methods developed by researchers at the U.S. Department of Agriculture's Forest Service, specifically for use in the U.S. Greenhouse Gas Inventory.

The methods used in the U.S. Greenhouse Gas Inventory have implications for how states develop their inventories. Since the mid-1990s, EPA has supported state and local governments in developing GHG inventories. One of the principles of this capacity-building work is that state inventories should remain as consistent and comparable as possible with the U.S. National Inventory and those of other states. Consistency allows for easier comparison between individual state inventories and the Inventory of U.S. Greenhouse Gas Emissions and Sinks (U.S. Inventory).

5. Complete Characterization of Greenhouse Gas Emissions and Sinks for Landfills

Inventories are organized according to a set of principles that group emissions and sinks mostly by physical processes rather than economic sectors. As a result, to develop a straightforward and comprehensive analysis of greenhouse gases for specific sectors, in some cases it is necessary to compile data from various components or chapters of an inventory. The waste management sector is a case in point. In the U.S. Inventory, combustion of fossil-derived waste is reported in the "Energy" chapter of the inventory; landfill carbon storage is reported in the "Land Use, Land-Use Change, and Forestry" chapter; and methane emissions from landfills and compost are reported in the "Waste" chapter.

[2] "Stock change" refers to the change, from year to year, in the amount of carbon stored in a given "pool" (such as carbon in the wood used in buildings, or carbon in landfills). Thus, the key issue is not how long the carbon ultimately persists in any given pool, but whether there is a net increase from year to year, i.e., a positive stock change.

Given that both voluntary and regulatory efforts to address climate change are likely to be focused on specific sectors, inventories provide an important foundation for developing mitigation strategies. Inventory compilers who adhere to the IPCC reporting guidelines—and the structure of the U.S. Inventory, which is corollary to the IPCC framework—cannot fix the organizational problem described above, but they can and should report emissions and sinks so that a complete sectoral pictures of a given source category can be developed. Therefore, we suggest that to provide a complete picture of all human-related emissions and sinks within the waste management sector, landfill carbon storage calculations should be reported along with emissions of methane.

6. Conclusion

The landfilling of harvested wood products, yard trimmings, and food scraps stores a significant amount of carbon that would otherwise decompose and release carbon to the atmosphere. Thus landfill carbon storage should be accounted for in greenhouse gas inventories. The Intergovernmental Panel on Climate Change recommends doing so, and the EPA follows that recommendation in preparing the annual U.S. national greenhouse gas inventory by accounting for carbon storage associated with disposal of harvested wood products, yard trimmings, and food scraps in landfills. For the sake of transparency, comparability, consistency, and completeness, we believe that all state inventories should do the same.

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